

TECHNIQUE AND INTERFACE FOR STORAGE SYSTEM RESOURCE ASSIGNMENT

Field of the Invention:

- 5 The present invention relates to the field of design of computer systems and data storage systems. More particularly, the present invention relates to the field of techniques and user interfaces for the design and configuration of computer systems and data storage systems.

10 Background of the Invention:

A computer system including a data storage system may be designed and configured for a specific application. This generally requires that a skilled designer rely on experience while making design choices based on requirements for the storage system and on possible memory devices to be incorporated into the storage system.

- 15 Particularly, a variety of different memory devices form the building blocks of modern data storage systems. Specific devices can be based on, for example, optical, magnetic and/or electronic storage technologies and may include solid-state memory devices, magnetic tape drives and optical or magnetic disk drives and arrays. Memory devices can be further characterized, for example, by capacity, levels or
- 20 types of redundancy provided (e.g., RAID-1 or RAID-5), bandwidth, cost, latency (e.g., read latency and/or write latency), and whether they are read and write capable, read-only capable, dynamic, static, volatile or non-volatile.

- Additionally, storage capacity and other resources of the data storage system may be assigned to one or more applications that are to be served by the data storage
- 25 system. For example, various data elements, such as files or databases, may be placed in a storage system in a number of different ways. One form of this may be referred to as the “bin-packing problem,” the goal of which is to fit data elements of various different sizes into storage devices of given sizes, while minimizing wasted space. The assignment task quickly becomes more complicated, however, when one attempts
- 30 to apply additional constraints. For example, certain applications may have minimum requirements in terms of storage capacity, access times and so forth.

Since storage system resources are most often limited, the design process typically includes making a number of trade-offs with respect to the system resources. Further, design trade-offs that are appropriate in one context may not be appropriate

in other contexts. For example, in a storage system for serving Internet downloads, high bandwidth and fault tolerance may be priorities, whereas, in a storage system for archiving data records, low cost and low power consumption may be priorities. However, the effects of some trade-offs may not be readily apparent, particularly where a single storage system serves multiple different applications. For example, when storage system resources are allocated to one application, the effect this will have on other applications served by the storage system may not always be readily apparent, even to a skilled designer.

Modeling tools are known for predicting the performance of data storage systems. However, the capabilities of such modeling tools are limited. For example, they do not provide a solution when predicted performance falls short of requirements.

Because specialized skills are required to design and configure a storage system, including assigning storage system resources to applications and verifying that the design meets requirements, such specially-designed storage systems tend to be expensive. Further, due to lack of a systematic approach, the design process can be time consuming and may yield a less-than-optimal result.

Accordingly, it would be desirable to provide a technique for the design and configuration of a data storage system that is more systematic, more likely to yield optimal results and that is less time-consuming than conventional design techniques.

Summary of the Invention:

The present invention is a technique and user interface for the design and configuration of computer systems and, particularly, for the assignment of data storage system resources. The invention allows a user to make design selections and, then, automatically provides an indication to the user of the effect of the selections. For example, various performance parameters for each of several applications served by a storage system may be displayed graphically as a chart. In response to the user adjusting a parameter for one application, the invention determines what effect this change will have on the other displayed parameters. The effects may then be displayed graphically in the chart. The invention is particularly useful for allocating data storage system resources among several different applications.

In one aspect of the invention, a method of and an apparatus for assigning resources for a computer system design are provided. Desired levels of specified

performance parameters for a computer system design are received from a user via a user interface to a computer system. The design is developed. Levels of performance parameters for the design are predicted. The predicted levels of performance parameters are compared to the desired levels of performance parameters. When the predicted levels are lower than the desired levels, the design is modified by the computer system.

The computer system design may include a design for data storage system. Developing the computer system design may include assigning system resources to applications to be served by the design. A design tool operating on a computer system may perform the assigning. The design may be modified by reducing the desired levels of performance parameters. The reductions to the desired performance parameters may be based on utility functions which may be received via the user interface to the computer system. The user interface may be a graphical user interface. For example, the user may manipulate heights of bar graphs shown on a display of the computer system to specify the desired levels. Each bar graph may include indicia of the corresponding desired level of the performance parameter and indicia of the corresponding predicted level of the performance parameter. For example, different colors may be used to indicate the level of each.

Predicting the performance of the design and comparing its predicted performance may be repeated after the design is modified. In addition, the user may be notified when the predicted levels are lower than the desired levels after the design is modified.

The invention provides an easy-to-use technique for assigning resources in a data storage system based on desired levels of performance and on utility information provided by the user.

Brief Description of the Drawings:

Figure 1 illustrates an exemplary graphic display in accordance with the present invention;

Figures 2A-C illustrate exemplary utility functions in accordance with the present invention;

Figure 3 illustrates a block schematic diagram of a general-purpose computer system by which the present invention may be implemented; and

Figure 4 illustrates a flow diagram of a process for assigning system resources in accordance with the present invention.

Detailed Description of a Preferred Embodiment:

The present invention provides a technique and user interface for the design and configuration of computer systems and, particularly, for the assignment of data storage system resources. A user, such as a system designer or administrator, is typically provided with a set of applications (e.g., software applications) that require resources of a computer system and, particularly, its data storage system resources. Thus, a single computer (or storage system) may serve one or more applications. Each application will generally have requirements, such as those relating to bandwidth, request rates, response times, and so forth. The resources of the computer system and, particularly, data storage system resources, such as disks, cache memory, parity groups, back-end bus traffic, and so forth, are to be assigned to the applications in an attempt to meet the requirements of each application.

The invention provides an interface, such as via a computer system monitor, mouse and keyboard, through which the user may receive certain information regarding the design for the computer system, its configuration and its predicted performance. The term "performance" is used herein in its ordinary sense and includes parameters that tend to characterize the system, such as its size, weight, power consumption, availability, cost, bandwidth, latency, and so forth. Information may be provided to the user in numeric or graphic form and may be displayed on the computer monitor. As an example of a numeric display, a table or spreadsheet that includes various data storage system parameters that may be displayed to the user. As an example of a graphic display, a chart or graph may be displayed which represents the various parameters. In addition, the user may provide input which affects the design, configuration and performance of the computer system under design. The input may be provided by the user via the mouse and/or keyboard of the computer system.

Figure 1 illustrates an exemplary graphic display 100 in accordance with the present invention. As shown in Figure 1, parameters of three applications (Application #1, Application #2 and Application #3) are represented as vertical bars 102-118 where the height of a bar indicates the value of the corresponding parameter. The parameters shown in Figure 1 include bandwidth, response time and capacity; however, it will be apparent that other parameters may be selected. As shown in

Figure 1, vertical bar 102 may represent the amount of bandwidth allocated to Application #1; vertical bar 104 may represent the response time for read or write requests initiated by Application #1 and vertical bar 106 may represent the amount of storage capacity allocated to Application #1. Similarly, vertical bars 108-112 may represent parameters for Application #2, while vertical bars 114 may represent parameters for Application #3. As explained herein, the displayed levels may be desired levels and/or predicted levels.

It will be apparent that the arrangement of the display 100 of Figure 1 is exemplary and that other arrangements may be selected. For example, other parameters, such as request rate or throughput may be displayed. As another example, parameters for the applications may be represented by one or more pie charts or tables. Preferably, the displayed parameters represent measures of performance that are relevant to the applications served by the computer system or data storage system under design.

As mentioned, the user may also provide input via the display 100. In one embodiment, the user may position a cursor over a selected one of the vertical bars 102-118, depress control key, such as a mouse button, and then lengthen or shorten the bar by moving the cursor (this technique may be referred to as “clicking and dragging”). Alternate input may also be accepted, such as by the user typing desired numeric values for selected parameters. Accordingly, the invention provides an interface that is easy-to-use in that it readily displays relevant information and easily accepts input from the user.

The parameters shown on the display 100 relate to applications to be served by a computer or data storage system that may be under design. Thus, in response to a user changing the displayed parameters, the design may be altered to accommodate the change. For example, the storage system design may only have a specified total amount of capacity. Accordingly, if the user changes the capacity parameter for Application #1, this may affect the storage capacity available to Applications #2 and #3. A design tool may be employed to make modifications to the design.

The altered design may then be evaluated to determine whether it still meets the requirements of the applications served by the storage system. The user may then be informed of the results (e.g., whether the change is met with success or failure). For example, if the user increases the capacity parameter for Application #1 and this increase results in a reduction of the capacity available to Applications #2 and #3 such

that their capacity requirements may still be met using a modified design, the display 100 may be updated to reflect new capacity parameters for Applications #2 and #3. Alternately, if this increase would not leave sufficient capacity for either Application #2 or #3, then a message may appear on the display 100 to inform the user of this.

For example, the message: “insufficient resources available” may appear. Further, the parameters for which the application requirements could not be met may change color on the display 100. In addition, how much of the requirement that could not be met may be represented by using two colors: one showing the amount of a parameter available to an application and the other showing a difference between the amount of the parameter available and the minimum requirement for the application.

In one embodiment, if a desired change to a parameter for an application is met with failure, the requirements for the other applications may be modified in order to accommodate the user’s desired changes. However, to accomplish this, certain trade-offs may have to be made to the performance goals for the applications. One approach is to reduce the corresponding delivered performance parameter for all the other applications evenly (e.g., by the same percentage or amount). For example, assume that the user desires to increase the capacity of Application #1, which requires freeing up three Gigabytes. Assume also that Application #2 has a requirement of ten Gigabytes and that Application #3 has a requirement of twenty Gigabytes. Under these circumstances, one option is to reduce the requirement of Application #2 by one Gigabyte (i.e. 10% of ten Gigabytes) and to reduce the requirement of Application #3 by two Gigabytes (i.e. 10% of twenty Gigabytes). Another option is to reduce the capacity requirement for each of Applications #2 and #3 by the same amount (one and one-half Gigabytes).

Another approach is to reduce only the requirement for the application whose requirement is highest. For example, assume that the user desires to increase the capacity of Application #1 by three Gigabytes. Assume also that Application #2 has a requirement of ten Gigabytes and that Application #3 has a requirement of twenty Gigabytes. Under these circumstances, one option is to reduce the requirement of Application #3 by the entire three Gigabytes since Application #3 has the highest requirement. This approach will tend to reduce the requirements of the other applications to the same level. Thus, if the capacity requirement for Application #3 is reduced to ten Gigabits, then any further reductions may be shared equally by Applications #2 and #3.

When confronted with a failed attempt, the user may be provided the ability to select from one of these schemes for trading-off the levels of performance parameters. Alternately, one approach may be pre-selected and, thus, may be performed without further input from the user.

Still another approach is to obtain input from the user regarding the relative importance of the requirements or goals for each application. For example, the user may specify certain "utility functions" for each parameter. A utility function represents how much utility (or value) is attached to various levels of the performance parameters.

Figures 2A-C illustrate exemplary utility functions in accordance with the present invention. As shown in Figures 2A-C, each utility function may be represented as a function in two-dimensions with a performance parameter (e.g., bandwidth) on the X-axis and a corresponding delivered utility on the Y-axis. More particularly, Figure 2A illustrates that the user has determined that for a particular application and performance parameter, utility is proportional to bandwidth. In other words, the faster this application operates, the greater the utility. Thus, Figure 2A illustrates a linear relationship between the performance parameter and its utility.

Figure 2B illustrates a situation in which the user has determined that the faster the application operates, the greater the utility except that once the bandwidth reaches a certain point, additional bandwidth is less useful. Thus, Figure 2B illustrates a linear relationship between the performance parameter and its utility, except that the slope is reduced after a certain level of the parameter is reached. An example suitable for this function may be an order entry system. This is because an ability to handle normal ordering traffic is very important. It would also be helpful, but not as important, to also have an ability to handle peak loads.

Figure 2C illustrates a situation in which there is no utility below a certain bandwidth, but that once that level is reached, a certain level of utility is achieved. This first level of utility is shown in Figure 2C by vertical portion of the curve. Then, as bandwidth increases, so does utility. This is shown by the sloping portion of the curve. When a certain point is reached, utility no longer increases. This is shown by the horizontal portion of the curve. An example suitable for this function may be a video server. This is because the lowest bandwidth may be necessary for minimal image quality. As the bandwidth goes up, so does image quality. However, a point is

eventually reached where the storage system is no longer the limiting factor on image quality.

It will be apparent that the utility functions illustrated in Figures 2A-C are exemplary and that other functions may be selected. Further, utility functions may be multi-dimensional. For example, the utility of certain performance parameters, such as bandwidth and response time, may be interdependent.

As explained herein, by specifying utility functions, desirable trade-offs can be made when resources are limited, without requiring further input from the user. More particularly, given user-specified relationships between utility and levels of certain performance parameters, appropriate trade-offs can be made so as to maximize the utility provided while allocating limited resources.

Figure 3 illustrates a block schematic diagram of a general-purpose computer system 300 by which the present invention may be implemented. The computer system 300 may include a general-purpose processor 302, a memory 304, such as persistent memory (e.g., a hard disk for program memory) and transitory memory (e.g., RAM), a communication bus 306, and input/output devices 308, such as a keyboard, monitor and mouse. The computer system 300 is conventional. As such, it will be apparent that the system 300 may include more or fewer elements than shown in Figure 3 and that other elements may be substituted for those illustrated in Figure 3. Software for implementing the present invention, such as assigning data storage system resources in accordance with the present invention and for providing the user interface of the present invention, may be stored in the memory 304 in accordance with the present invention. Further, the display 100 of Figure 1 may be provided by the monitor 308 of the system 300.

Figure 4 illustrates a flow diagram 400 of a process for assigning resources for a computer system design in accordance with the present invention. As mentioned, a software program which implements the process of Figure 4 may be stored in the memory 304 of the computer system 300 of Figure 3 for causing the processor 302 to perform the steps of the process. Accordingly, the process is preferably performed automatically, such as by the computer system 300, however, it will be apparent that one or more of the steps may be performed manually.

Referring to Figure 4, program flow begins in a start state 402. From the state 402, program flow moves to a state 404. In the state 404, the user may specify a scheme for trading-off system resources should the need arise. For example, utility

functions, such as those illustrated in Figures 2A-C, may be captured and stored for later use (e.g., in the memory 304 of Figure 3). Thus, the user may specify the utility functions for various performance parameters of each application to be served by the computer or data storage system under design. Alternately, the user may select from a number of pre-configured utility functions. For example, the utility functions illustrated in Figures 2A-C may be displayed on the display 100 (Figure 1) along with a menu of applications and performance parameters. Then, the user may select appropriate ones by "clicking" on them.

From the state 404, program flow moves to a state 406 in which application goals may be captured and/or modified. In addition to the utility functions, the desired levels of performance parameters may be stored in the memory 304 of the computer 300. For example, the user may specify desired measures of performance for each application by making selections from a menu shown on the display 100 (Figure 1). As shown in Figure 1, the selections may include bandwidth, response time, capacity and so forth. In the state 406, the user may also set desired levels for each selection. For example, the user may click and drag the bars 102-118 (Figure 1) to the desired levels.

From the state 406, program flow moves to a state 408. In the state 408, a determination may be made as to whether to modify the design of the system based on the utility functions set in the state 404 and/or the performance levels set in the state 406. In one embodiment, this determination is made by the user; if no affirmative input from the user is provided, then the default condition is a negative determination. In which case, program flow moves to a state 410.

In the state 410, a determination may be made as to whether to finalize the current design of the computer or storage system. In one embodiment, this determination is made by the user; if no affirmative input from the user is provided, then the default condition is a negative determination. In which case, program flow returns to the state 404.

Accordingly, program flow remains in a loop which includes the states 404, 406, 408 and 410 until the user decides to either modify the design or finalize the current design. While in the loop, the user may make as many changes to the utility functions (in state 404) or to the performance levels (in state 406) as desired.

Once the user decides to modify the design, program flow moves from the state 408 to a state 412. In the state 412, a design tool may be invoked to develop a

design for the computer or its storage system based in the desired performance levels. Any suitable conventional design tool may be used for this purpose, such as a computer-aided design tool. In a preferred embodiment, the design tool is similar to the one disclosed in co-pending U.S. Patent Application Serial No. _____, of
 5 Eric Anderson, filed on August 7, 2001, and entitled "SIMULTANEOUS ARRAY CONFIGURATION AND STORE ASSIGNMENT FOR A DATA STORAGE SYSTEM," the contents of which are hereby incorporated by reference. Further, manual design techniques may be employed in the state 412, such that the system is designed completely or partially "by hand."

10 From the state 412, program flow moves to a state 414 in which a performance modeling tool may be invoked in order to characterize the design developed in the state 412. The tool invoked in the state 414 preferably provides a prediction of the actual levels of performance that may be achieved by the design developed in the state 412. For example, if one of the performance goals specified in the state 406 is
 15 bandwidth, then the tool invoked in the state 414 preferably provides a predicted level of bandwidth for the design developed in the state 412. The tool invoked in the state 412 may be any suitable conventional modeling tool. In a preferred embodiment, the modeling tool is similar to the one disclosed in co-pending U.S. Patent Application Serial No. 09/843,903, filed April 30, 2001, of Mustafa Uysal et al., and entitled
 20 "Method and Apparatus for Morphological Modeling of Complex Systems to Predict Performance," the contents of which are hereby incorporated by reference. Further, manual modeling techniques may be employed in the state 414, such that the system is modeled completely or partially "by hand." Also, actual performance of a data storage system may be measured in the state 406.

25 From the state 414, program flow moves to a state 416. In the state 416, a comparison may be made between the desired levels of the performance parameters set in the state 406 and the levels achieved in the state 414. From the state 416 program flow moves to a state 418 where a determination may be made as to the results of the comparison performed in the state 416. If the desired levels were not
 30 achieved, then program flow may move to a state 420.

In the state 420, the performance levels set in the state 406 may be adjusted based on the utility functions set in the state 404. Thus, where resources of the storage system are limited, trade-offs can be made in the state 420. For example, assuming the total available storage capacity of the storage system under design is

exceeded by the amount of capacity the user desires to provide to each application, a trade-off will have to be made. If the utility function for one of the applications is flat (horizontal) beyond a certain capacity level (e.g., similar to the curve in Figure 2C), this means that the capacity allocated to that application can be reduced to that level in the state 420 with no loss of utility. As another example, if all the applications have the same utility function for capacity as shown in Figure 2A (and with the same slope), then the capacity for each may be reduced by the same amount in the state 420. Numerous other trade-offs relative to the limited resource can be made in the state 420.

From the state 420, program flow may return to the state 412. Then, the newly adjusted performance levels (in state 420) may be used to develop a new design for the computer or storage system (in state 422) and newly achieved performance results compared to the desired performance levels 416. This program loop (including states 420, 412, 414, 416 and 418) may continue until the desired levels are achieved. Thus, if in the state 420, it is determined that the desired performance levels (as set in the state 404 (or modified in the state 420), are met, then program flow may move from the state 420 to a state 422.

In the state 422, the current performance levels that can be achieved (as predicted in state 416) may be shown on the display 100 (Figure 1). From the state 422, program flow returns to the first loop (including states 402, 404, 406, 408 and 410) where the user may make further adjustments to the utility functions (404) and the desired performance levels (state 406).

Note that when program flow is in the loop that includes states 420, 412, 414, 416 and 418, with each pass through the loop beyond two or three passes, it becomes increasingly less likely that the desired performance goals can be met without making more drastic trade-offs. Thus, rather than making such drastic trade-offs in the state 420, program flow may return to the first loop (including states 402, 404, 406, 408 and 410) where the user may make these trade-offs manually by changing the utility functions and/or the desired performance levels. Under these circumstances, the levels displayed in the state 422 may show how much of a requirement that could not be met such as by using two colors, as explained above in reference to Figure 1.

When a satisfactory design is achieved and the user no longer wishes to make any additional changes, the user may indicate that the process is complete. For

example, the user may click on an icon on the display 100 labeled “done.” Then, program flow moves from the state 410 to a state 424. In the state 424, the design may be completed. For example, a physical data storage system may be configured as indicated by the design tool invoked in the state 412. From the state 424, program

5 flow may terminate in a state 426.

While the foregoing has been with reference to particular embodiments of the invention, it will be appreciated by those skilled in the art that changes in these embodiments may be made without departing from the principles and spirit of the invention, the scope of which is defined by the appended claims.

101
102
103
104
105
106
107
108
109
110
111
112
113
114
115
116
117
118
119
120
121
122
123
124
125
126
127
128
129
130
131
132
133
134
135
136
137
138
139
140
141
142
143
144
145
146
147
148
149
150
151
152
153
154
155
156
157
158
159
160
161
162
163
164
165
166
167
168
169
170
171
172
173
174
175
176
177
178
179
180
181
182
183
184
185
186
187
188
189
190
191
192
193
194
195
196
197
198
199
200
201
202
203
204
205
206
207
208
209
210
211
212
213
214
215
216
217
218
219
220
221
222
223
224
225
226
227
228
229
230
231
232
233
234
235
236
237
238
239
240
241
242
243
244
245
246
247
248
249
250
251
252
253
254
255
256
257
258
259
260
261
262
263
264
265
266
267
268
269
270
271
272
273
274
275
276
277
278
279
280
281
282
283
284
285
286
287
288
289
290
291
292
293
294
295
296
297
298
299
300
301
302
303
304
305
306
307
308
309
310
311
312
313
314
315
316
317
318
319
320
321
322
323
324
325
326
327
328
329
330
331
332
333
334
335
336
337
338
339
340
341
342
343
344
345
346
347
348
349
350
351
352
353
354
355
356
357
358
359
360
361
362
363
364
365
366
367
368
369
370
371
372
373
374
375
376
377
378
379
380
381
382
383
384
385
386
387
388
389
390
391
392
393
394
395
396
397
398
399
400
401
402
403
404
405
406
407
408
409
410
411
412
413
414
415
416
417
418
419
420
421
422
423
424
425
426
427
428
429
430
431
432
433
434
435
436
437
438
439
440
441
442
443
444
445
446
447
448
449
450
451
452
453
454
455
456
457
458
459
460
461
462
463
464
465
466
467
468
469
470
471
472
473
474
475
476
477
478
479
480
481
482
483
484
485
486
487
488
489
490
491
492
493
494
495
496
497
498
499
500
501
502
503
504
505
506
507
508
509
510
511
512
513
514
515
516
517
518
519
520
521
522
523
524
525
526
527
528
529
530
531
532
533
534
535
536
537
538
539
540
541
542
543
544
545
546
547
548
549
550
551
552
553
554
555
556
557
558
559
560
561
562
563
564
565
566
567
568
569
570
571
572
573
574
575
576
577
578
579
580
581
582
583
584
585
586
587
588
589
590
591
592
593
594
595
596
597
598
599
600
601
602
603
604
605
606
607
608
609
610
611
612
613
614
615
616
617
618
619
620
621
622
623
624
625
626
627
628
629
630
631
632
633
634
635
636
637
638
639
640
641
642
643
644
645
646
647
648
649
650
651
652
653
654
655
656
657
658
659
660
661
662
663
664
665
666
667
668
669
670
671
672
673
674
675
676
677
678
679
680
681
682
683
684
685
686
687
688
689
690
691
692
693
694
695
696
697
698
699
700
701
702
703
704
705
706
707
708
709
710
711
712
713
714
715
716
717
718
719
720
721
722
723
724
725
726
727
728
729
730
731
732
733
734
735
736
737
738
739
740
741
742
743
744
745
746
747
748
749
750
751
752
753
754
755
756
757
758
759
760
761
762
763
764
765
766
767
768
769
770
771
772
773
774
775
776
777
778
779
780
781
782
783
784
785
786
787
788
789
790
791
792
793
794
795
796
797
798
799
800
801
802
803
804
805
806
807
808
809
810
811
812
813
814
815
816
817
818
819
820
821
822
823
824
825
826
827
828
829
830
831
832
833
834
835
836
837
838
839
840
841
842
843
844
845
846
847
848
849
850
851
852
853
854
855
856
857
858
859
860
861
862
863
864
865
866
867
868
869
870
871
872
873
874
875
876
877
878
879
880
881
882
883
884
885
886
887
888
889
890
891
892
893
894
895
896
897
898
899
900
901
902
903
904
905
906
907
908
909
910
911
912
913
914
915
916
917
918
919
920
921
922
923
924
925
926
927
928
929
930
931
932
933
934
935
936
937
938
939
940
941
942
943
944
945
946
947
948
949
950
951
952
953
954
955
956
957
958
959
960
961
962
963
964
965
966
967
968
969
970
971
972
973
974
975
976
977
978
979
980
981
982
983
984
985
986
987
988
989
990
991
992
993
994
995
996
997
998
999
1000
1001
1002
1003
1004
1005
1006
1007
1008
1009
1010
1011
1012
1013
1014
1015
1016
1017
1018
1019
1020
1021
1022
1023
1024
1025
1026
1027
1028
1029
1030
1031
1032
1033
1034
1035
1036
1037
1038
1039
1040
1041
1042
1043
1044
1045
1046
1047
1048
1049
1050
1051
1052
1053
1054
1055
1056
1057
1058
1059
1060
1061
1062
1063
1064
1065
1066
1067
1068
1069
1070
1071
1072
1073
1074
1075
1076
1077
1078
1079
1080
1081
1082
1083
1084
1085
1086
1087
1088
1089
1090
1091
1092
1093
1094
1095
1096
1097
1098
1099
1100
1101
1102
1103
1104
1105
1106
1107
1108
1109
1110
1111
1112
1113
1114
1115
1116
1117
1118
1119
1120
1121
1122
1123
1124
1125
1126
1127
1128
1129
1130
1131
1132
1133
1134
1135
1136
1137
1138
1139
1140
1141
1142
1143
1144
1145
1146
1147
1148
1149
1150
1151
1152
1153
1154
1155
1156
1157
1158
1159
1160
1161
1162
1163
1164
1165
1166
1167
1168
1169
1170
1171
1172
1173
1174
1175
1176
1177
1178
1179
1180
1181
1182
1183
1184
1185
1186
1187
1188
1189
1190
1191
1192
1193
1194
1195
1196
1197
1198
1199
1200
1201
1202
1203
1204
1205
1206
1207
1208
1209
1210
1211
1212
1213
1214
1215
1216
1217
1218
1219
1220
1221
1222
1223
1224
1225
1226
1227
1228
1229
1230
1231
1232
1233
1234
1235
1236
1237
1238
1239
1240
1241
1242
1243
1244
1245
1246
1247
1248
1249
1250
1251
1252
1253
1254
1255
1256
1257
1258
1259
1260
1261
1262
1263
1264
1265
1266
1267
1268
1269
1270
1271
1272
1273
1274
1275
1276
1277
1278
1279
1280
1281
1282
1283
1284
1285
1286
1287
1288
1289
1290
1291
1292
1293
1294
1295
1296
1297
1298
1299
1300
1301
1302
1303
1304
1305
1306
1307
1308
1309
1310
1311
1312
1313
1314
1315
1316
1317
1318
1319
1320
1321
1322
1323
1324
1325
1326
1327
1328
1329
1330
1331
1332
1333
1334
1335
1336
1337
1338
1339
1340
1341
1342
1343
1344
1345
1346
1347
1348
1349
1350
1351
1352
1353
1354
1355
1356
1357
1358
1359
1360
1361
1362
1363
1364
1365
1366
1367
1368
1369
1370
1371
1372
1373
1374
1375
1376
1377
1378
1379
1380
1381
1382
1383
1384
1385
1386
1387
1388
1389
1390
1391
1392
1393
1394
1395
1396
1397
1398
1399
1400
1401
1402
1403
1404
1405
1406
1407
1408
1409
1410
1411
1412
1413
1414
1415
1416
1417
1418
1419
1420
1421
1422
1423
1424
1425
1426
1427
1428
1429
1430
1431
1432
1433
1434
1435
1436
1437
1438
1439
1440
1441
1442
1443
1444
1445
1446
1447
1448
1449
1450
1451
1452
1453
1454
1455
1456
1457
1458
1459
1460
1461
1462
1463
1464
1465
1466
1467
1468
1469
1470
1471
1472
1473
1474
1475
1476
1477
1478
1479
1480
1481
1482
1483
1484
1485
1486
1487
1488
1489
1490
1491
1492
1493
1494
1495
1496
1497
1498
1499
1500
1501
1502
1503
1504
1505
1506
1507
1508
1509
1510
1511
1512
1513
1514
1515
1516
1517
1518
1519
1520
1521
1522
1523
1524
1525
1526
1527
1528
1529
1530
1531
1532
1533
1534
1535
1536
1537
1538
1539
1540
1541
1542
1543
1544
1545
1546
1547
1548
1549
1550
1551
1552
1553
1554
1555
1556
1557
1558
1559
1560
1561
1562
1563
1564
1565
1566
1567
1568
1569
1570
1571
1572
1573
1574
1575
1576
1577
1578
1579
1580
1581
1582
1583
1584
1585
1586
1587
1588
1589
1590
1591
1592
1593
1594
1595
1596
1597
1598
1599
1600
1601
1602
1603
1604
1605
1606
1607
1608
1609
1610
1611
1612
1613
1614
1615
1616
1617
1618
1619
1620
1621
1622
1623
1624
1625
1626
1627
1628
1629
1630
1631
1632
1633
1634
1635
1636
1637
1638
1639
1640
1641
1642
1643
1644
1645
1646
1647
1648
1649
1650
1651
1652
1653
1654
1655
1656
1657
1658
1659
1660
1661
1662
1663
1664
1665
1666
1667
1668
1669
1670
1671
1672
1673
1674
1675
1676
1677
1678
1679
1680
1681
1682
1683
1684
1685
1686
1687
1688
1689
1690
1691
1692
1693
1694
1695
1696
1697
1698
1699
1700
1701
1702
1703
1704
1705
1706
1707
1708
1709
1710
1711
1712
1713
1714
1715
1716
1717
1718
1719
1720
1721
1722
1723
1724
1725
1726
1727
1728
1729
1730
1731
1732
1733
1734
1735
1736
1737
1738
1739
1740
1741
1742
1743
1744
1745
1746
1747
1748
1749
1750
1751
1752
1753
1754
1755
1756
1757
1758
1759
1760
1761
1762
1763
1764
1765
1766
1767
1768
1769
1770
1771
1772
1773
1774
1775
1776
1777
1778
1779
1780
1781
1782
1783
1784
1785
1786
1787
1788
1789
1790
1791
1792
1793
1794
1795
1796
1797
1798
1799
1800
1801
1802
1803
1804
1805
1806
1807
1808
1809
1810
1811
1812
1813
1814
1815
1816
1817
1818
1819
1820
1821
1822
1823
1824
1825
1826
1827
1828
1829
1830
1831
1832
1833
1834
1835
1836
1837
1838
1839
1840
1841
1842
1843
1844
1845
1846
1847
1848
1849
1850
1851
1852
1853
1854
1855
1856
1857
1858
1859
1860
1861
1862
1863
1864
1865
1866
1867
1868
1869
1870
1871
1872
1873
1874
1875
1876
1877
1878
1879
1880
1881
1882
1883
1884
1885
1886
1887
1888
1889
1890
1891
1892
1893
1894
1895
1896
1897
1898
1899
1900
1901
1902
1903
1904
1905
1906
1907
1908
1909
1910
1911
1912
1913
1914
1915
1916
1917
1918
1919
1920
1921
1922
1923
1924
1925
1926
1927
1928
1929
1930
1931
1932
1933
1934
1935
1936
1937
1938
1939
1940
1941
1942
1943
1944
1945
1946
1947
1948
1949
1950
1951
1952
1953
1954
1955
1956
1957
1958
1959
1960
1961
1962
1963
1964
1965
1966
1967
1968
1969
1970
1971
1972
1973
1974
1975
1976
1977
1978
1979
1980
1981
1982
1983
1984
1985
1986
1987
1988
1989
1990
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
2020
2021
2022
2023
2024
2025
2026
2027
2028
2029
2030
2031
2032
2033
2034
2035
2036
2037
2038
2039
2040
2041
2042
2043
2044
2045
2046
2047
2048
2049
2050
2051
2052
2053
2054
2055
2056
2057
2058
2059
2060
2061
2062
2063
2064
2065
2066
2067
2068
2069
2070
2071
2072
2073
2074
2075
2076
2077
2078
2079
2080
2081
2082
2083
2084
2085
2086
2087
2088
2089
2090
2091
2092
2093
2094
2095
2096
2097
2098
2099
2100
2101
2102
2103
2104
2105
2106
2107
2108
2109
2110
2111
2112
2113
2114
2115
2116
2117
2118
2119
2120
2121
2122
2123
2124
2125
2126
2127
2128
2129
2130
2131
2132
2133
2134
2135
2136
2137
2138
2139
2140
2141
2142
2143
2144
2145
2146
2147
2148
2149
2150
2151
2152
2153
2154
2155
2156
2157
2158
2159
2160
2161
2162
2163
2164
2165
2166
2167
2168
2169
2170
2171
2172
2173
2174
2175
2176
2177
2178
2179
2180
2181
2182
2183
2184
2185
2186
2187
2188
2189
2190
2191
2192
2193
2194
2195
2196
2197
2198
2199
2200
2201
2202
2203
2204
2205
2206
2207
2208
2209
2210
2211
2212
2213
2214
2215
2216
2217
2218
2219
2220
2221
2222
2223
2224
2225
2226
2227
2228
2229
2230
2231
2232
2233
2234
2235
2236
2237
2238
2239
2240
2241
2242
2243
2244
2245
2246
2247
2248
2249
2250
2251
2252
2253
2254
2255
2256
225